Effects of Driver Population on the Traffic Operational Performance of Signalized Intersections

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ABSTRACT

The current version of the *Highway Capacity Manual* does not account for the impact of varying driver populations in the analysis procedures for signalized intersections. This study analyzes the difference in saturation flow rates during different times of the day and days of the week. It is hypothesized that traffic streams exhibit different operational characteristics during different times of the day and days of the week due to varying motivational factors of the drivers. If this is the case, it might be appropriate to adjust the ideal saturation flow rate accordingly during capacity analysis of signalized intersections. In essence, one would be adjusting the saturation flow rate due to varying driver populations, as defined in terms of time of day and day of the week. After an initial investigation at one intersection, it was concluded that there are no significant differences in the operational performance of signalized intersections during different times of the day and days of the week. No differences were found in the mean saturation flow rates for the morning peak period as compared to the afternoon peak period. Likewise, no differences were found in the mean saturation flow rates for different weekdays, Monday through Friday. However, some differences were found in the distribution of headways throughout the week.

1. INTRODUCTION

The term, driver population, can be defined many ways in the field of transportation. In the context of traffic operations, driver population is typically defined in terms of weekday, commuter traffic and recreational traffic. The intent is to reflect the presence of unfamiliar drivers in the traffic stream. The impact is that traffic streams comprised of unfamiliar drivers operate differently.

A traffic stream consisting strictly of commuters uses the roadway more efficiently than a traffic stream comprised of recreational, or non-commuter traffic. Commuters who travel the same route daily to and from work become familiar with the roads along a particular route, or in a particular area. Consequently, commuters are more comfortable driving at closer headways and higher speeds than drivers who are traveling along the same roadway for the first time and are unfamiliar with the geometry, the traffic control, the environment, etc. Motivational factors may also influence the performance of the various driver populations.

Commuters may drive more aggressively on their way to work or on their way home, while non-commuters may be site seeing or on their way to the grocery store and may not be as concerned about their arrival times.

This study analyzes the difference in saturation flow rates during different times of the day and days of the week. Saturation flow rates at one signalized intersection in State College, Pennsylvania were collected during morning (7 am–9 am) and afternoon (4 pm–6 pm) weekday peak periods to investigate whether traffic streams behave differently at different times of the day and days of the week. If weekday commuters exhibit different driving behavior at signalized intersections during different times of the day and day of the week, it might be appropriate to adjust the ideal saturation flow rate accordingly during capacity analysis of signalized intersections. In essence, one would be adjusting the saturation flow rate due to varying driver populations, as defined in terms of time of day and day of the week.

1.1 Driver Population in the HCM

The most recent versions of the *Highway Capacity Manual* (HCM) utilize an adjustment factor in several of the procedures to account for the effects of different driver populations. Within the 1997 updates to the HCM, two chapters on uninterrupted flow consider the impact of driver population. Analysis procedures for basic freeway sections and ramps and ramp junctions utilize a driver population adjustment factor (f_p) to account for the impact of non-commuter traffic. The ideal driver population consists of 100 percent commuter traffic, corresponding to an adjustment factor of 1.0, while an adjustment factor between 0.85–0.99 is to be used to reflect the impact of recreational, or non-commuter traffic. This range indicates that capacities of freeways and ramps are reduced by up to 15 percent due to the characteristics of recreational, or non-commuter traffic. The remaining chapters in the HCM do not adjust the prevailing capacity to account for varying driver populations.

The f_p values in the 1997 updates to the HCM are slightly different from the values found in the 1994 and 1985 HCMs. In the 1994 HCM, f_p values range from 1.0 for weekday, commuter traffic to between 0.75 and 0.99 for recreational, or other traffic. In the 1985 HCM, the f_p value for commuter traffic is still 1.0, but the “other” category only has a range of 0.75 to 0.90. Driver population adjustments are not considered in the capacity analysis of ramps and ramps junctions in the 1985 HCM procedures.

As long ago as the 1960s, traffic engineers recognized the effects of driver population. Within the 1965 HCM, driver experience is identified as a general factor to be considered throughout an evaluation of the performance of ramps and ramp junctions. The 1965 HCM states that, “Interchanges carrying predominantly commuter traffic tend to have smoother operating characteristics than those carrying the same volume of tourist or long-distance traffic.”

1.2 Past Research of Driver Population

Some of the earliest interest in driver population can be traced back to studies performed by the California Department of Transportation (Lu et al. 1997). These studies, conducted in the early 1970s, indicated substantially lower capacities involving high levels of recreational traffic.

In Australia, Solomon (1976) found differences in the traditional speed flow relationships related to peak and off-peak driver populations. Solomon (1976) postulated that the different pattern was due to different driver populations. He claimed that the population of drivers on the road from 7:00 to 9:00 am was primarily commuters familiar with the driving conditions and the group of drivers on the road between 11:00 and 11:30 am probably consisted of shoppers, the elderly, and females in addition to those familiar with the freeway.

Early research in Europe (Traffic 1983) found conflicting results while investigating the effects of driver population. A French study showed a 17 percent drop in capacity on a Sunday evening compared to an average weekday on a motorway near Marseille. However, on the Boulevard Périférique, no such capacity variations could be found.

When Brilon and Ponzlet (1996) investigated average speeds along the German autobahn, they studied the effect of varying driver behavior and traffic mix. They found that during predominantly leisure traffic, such as on Sundays or during summer vacation, average speeds were lower.

Lu et al. (1997) examined the effect of driver population on the operations of freeway facilities in Florida and developed detailed f_p tables which correlated different driver population levels with the correspondent capacity reductions. Two different methodologies were used to develop the detailed f_p tables. One methodology utilized data from tourist surveys provided by the Office of Tourism Research, and the second approach calculated the f_p values based on traffic data obtained from permanent traffic count stations. The two methods produced different values for f_p. The range in f_p values went from an upper bound of 0.995 to a lower bound 0.844.

Zhou et al. (1999) developed driver population factors for the capacity analysis of signalized intersections in Florida. Zhou et al. (1999) found that when the non-local driver population level increased from 0% to 100%, the saturation flow rate was reduced to 81% of the ideal value calculated by the current HCM procedure. The difficulty of utilizing some of the results found by Zhou et al. (1999) is that engineers must know the percentage of non-local drivers in the traffic stream to properly account for their impacts. Where Zhou et al. (1999) made great strides in adding to the current practice was by calibrating non-local driver population adjustment factors by area type. The four area types identified included residential, business, shopping, and recreational areas. During capacity analyses, engineers can classify intersections according to one of these four area types and account for the impacts of non-local drivers in this manner. The population adjustment factors are 1.0–0.95, 0.99–0.90, 0.97–0.94, and 0.93–0.82 for residential, business, shopping, and recreational areas, respectively.

2. OBJECTIVE

The current version of the HCM does not account for the impact of varying driver populations in the analysis procedures for signalized intersections. The reason it is not accounted for is the lack of data. With the exception of the recent study by Zhou et al. (1999), which is a tremendous beginning to the research that needs to be conducted related to the effects of varying driver populations on the operational efficiency of signalized intersections, all prior studies on driver population concentrated on uninterrupted flow facilities. By not accounting for the impact of different driver populations, the analysis procedures for signalized intersections in the HCM disregard a factor that many generally agree affects capacity, at least in the case of uninterrupted flow facilities. As a matter of fact, even though the effects of driver population are accounted for in capacity procedures for freeways and ramps, it is questionable how the f_p values in the HCM were developed, whether they were developed from one of the studies previously mentioned or whether they were determined arbitrarily.

The objective of this research is to determine whether there is any significant difference in saturation flow rates at signalized intersections during different times of the day and different days of the week. If this is the case, then driver population could be characterized according to time of day and day of the week. Subsequently, the operational behavior of the different driver populations could be accounted for in the analysis procedures for signalized intersections.

It is hypothesized that traffic streams exhibit different operational characteristics during different times of the day and days of the week due to varying motivational factors of the drivers. It is realistic to assume that during the peak periods of the day commuters are in a different frame of mind while traveling to work as compared to their commute home. In one scenario, commuters may be more eager to return home in the evening than they are to get to work in the morning so the operations will be more efficient in the evening than the morning. In a second scenario, morning commuters are rushing to make it to work on time, and they are more relaxed on their commute home. In this instance, the morning operational performance might be more efficient than the evening. By investigating the operations over varying periods of the day and days of the week, it is possible to determine whether adjustments should be made in the operational analysis of signalized intersections due to the changing driver populations during the day and throughout the week.

Stated formally, this research seeks to answer two questions:

- Does the operational performance at signalized intersections change during the course of the day?
- Does the operational performance at signalized intersections change during the course of the week?

Operational performance is evaluated based on saturation flow rates. In other words, the saturation flow rates are compared to determine if there is any significant variance during different times of the day and days of the week.

One may argue that time of day does not impact the operational performance at signalized intersections based on previous research by Lee and Chen (1986). Lee and Chen (1986) investigated the influence of time of day on discharge headways at signalized intersections and concluded that time of day, signified by am and pm peak periods, had little influence on entering headways. However, Lee and Chen (1986) compared the mean entering headway for the first vehicle in the am queue and the first vehicle in the pm queue, the mean entering headway of the second vehicle in the am queue and the second vehicle in the pm queue, and so forth. From Lee and Chen’s 1986 study, it is not possible to determine whether there was a statistically significant difference in saturation flow rates between am and pm traffic.

3. METHODOLOGY

To fulfill the objective, the operational performance at the intersection of North Atherton Street and Park Avenue, located in State College, Pennsylvania, was analyzed. Viewing the operations at this intersection is particularly convenient because three cameras are installed at the intersection, and a real-time video signal is transmitted back to a research laboratory on the campus of Penn State University via a fiber connection. In the laboratory, the operations at the intersection can be viewed 24 hours a day, seven days a week, and can be recorded on video tape at any time. Figure 1 shows views from two of the cameras.

During the summer of 1999, between the dates of June 18^{th} and August 16^{th}, traffic operations were recorded for various research purposes. In total, approximately 135 hours of operations at the signal were recorded on video tape. These tapes were utilized to gather the data for this research.

Northbound Approach   Southbound Approach

FIGURE 1 Views from camera installations at North Atherton Street and Park Avenue.

The first step in this research was to catalog all the tapes according to time of day, day of the week, and approach. This process revealed how many different time periods and days of the week were actually recorded throughout the summer. Table 1 shows how many hours of operations were available for viewing from the respective time periods. These hours reflect typical weekday traffic under dry weather conditions. Recordings during non-typical week-

TABLE 1 Hours of Operations Recorded under Typical Traffic Conditions

Time Period	MON		TUES		WED		THUR		FRI		SAT		SUN	
	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB
7 am–9 am	6	0	6	4	6	6	4	4	10	6	0	0	0	0
4 pm–6 pm	6	0	10	6	6	6	4	2	12	6	0	0	0	0

days, such as Monday July 5th, and during adverse weather conditions were not considered appropriate for this research and are not included in Table 1.

The second step was to select which tapes should be viewed in order to collect the saturation flow rates and be able to compare operational performance between time of day and day of the week. As shown in Table 1, operations were recorded Monday through Friday, during both the morning and afternoon peak periods. Operations were not recorded during weekends, nor during off-peak periods. As a result, comparisons could not be made between saturation flow rates during peak vs. non-peak periods, nor between weekday vs. weekend flow rates. A total of 74 hours of operations were selected for viewing to collect data during as many different time periods, am and pm peaks, and days of the week, Monday through Friday, as possible.

The third task in the process involved identifying the type of data to be recorded from the video tapes. The following data were recorded:

- Date
- Day (Monday–Friday)
- Time (am or pm)
- Approach (NB or SB)
- Lane
- Number of vehicles in the queue
- Time between the 4th vehicle in the queue and the last vehicle in the queue.

The final tasks in the research were to collect the respective data from the tapes, record the data in spreadsheet format, and then analyze the data.

4. DATA COLLECTION

A total of 74 hours of operations were viewed to collect saturation headways in the through lanes at the intersection. On the northbound approach, there are two designated through lanes. On the southbound approach, there is one designated through lane and a shared through and right lane, but the shared lane operates more like a through lane. The right turn movement is minimal from the southbound approach. The westbound approach of the intersections has very minimal through traffic, and the west leg is one-way outbound so no data were collected from the east and west legs.

The saturation headways, and resultant flow rates, were collected according to the procedures described in the 1997 updates to the HCM. Saturation headways were calculated to the nearest hundredth of a second and directly input into a database. In some instances, the last vehicle(s) in the queue could not be seen either because of occlusion from other vehicles or the queue extended beyond the field of view of the camera. When this occurred, only those vehicles in the queue that could be seen were included in the saturation headway calculations.

5. DATA ANALYSIS

Saturation flow rates were calculated for 1176 queues of 5 vehicles or greater in the through lanes along the northbound and southbound approaches. Of these, 676 saturation headways were collected on the northbound approach and 500 were collected on the southbound approach. Table 2 shows the number of corresponding saturation flow rates collected during different times of the day and days of the week along each approach and also provides the mean saturation flow rate and standard deviation for the respective time periods. Only 6 observations were gathered on the northbound approach during the morning peak period. This was in part due to the signal coordination along the arterial and low traffic volume along the approach in the morning. On the southbound approach, no saturation flow rates were collected for Mondays. This was due in part to technical difficulties with the recording equipment and, in some instance, adverse weather conditions.

TABLE 2 Saturation Flow Rates Along the Northbound and Southbound Approaches

Northbound Approach															
	MON			**TUES**			**WED**			**THUR**			**FRI**		
	# OF OBS	AVG	ST DEV	# OF OBS	AVG	ST DEV	# OF OBS	AVG	ST DEV	# OF OBS	AVG	ST DEV	# OF OBS	AVG	ST DEV
Total	234	1814	297	133	1848	291	120	1783	304	68	1837	286	121	1796	312
AM	0	0	0	0	0	0	2	1574	234	0	0	0	4	1421	253
PM	234	1814	297	133	1848	291	118	1787	304	68	1837	286	117	1809	307
Total # of OBS = 676					Overall AVG = 1814					Overall ST DEV = 299					

Southbound Approach															
	MON			**TUES**			**WED**			**THUR**			**FRI**		
	# OF OBS	AVG	ST DEV	# OF OBS	AVG	ST DEV	# OF OBS	AVG	ST DEV	# OF OBS	AVG	ST DEV	# OF OBS	AVG	ST DEV
Total	0	0	0	157	1987	456	159	1947	452	93	1850	354	91	1958	369
AM	0	0	0	42	2049	496	58	2044	527	49	1889	312	24	1932	387
PM	0	0	0	115	1964	441	101	1891	395	44	1807	394	67	1967	365
Total # of OBS = 500					Overall AVG = 1943					Overall ST DEV = 424					

To determine whether there was a difference in saturation flow rates between time of the day and day of the week, it was necessary to determine whether the mean saturation flow rates were the same on both the northbound and southbound approaches. If the mean saturation flow rates were the same, then the data from both approaches could be combined to evaluate the main effects of time of day and day of the week. If the mean saturation flow rates were different, time of day and day of the week effects would have to be investigated separately for each approach.

A comparison of the mean saturation flow rates was performed using a standard *t*-test, comparing two population means. Holding the significance level at $\alpha = 0.05$, the *t*-test revealed that the saturation flow rates on the two approaches were significantly different. As a result, the data from each approach had to be analyzed separately. This was not anticipated because calculated saturation flow rates, according to the procedures from the 1997 HCM, were 1759 passenger cars per hour of effective green time per lane (pcphgpl) for the northbound approach and 1755 pcphgpl for the southbound approach which are essentially equivalent. For both approaches, the calculated saturation flow rates are less than the measured saturation flow rates.

5.1 Comparison of Mean Saturation Flow Rates

5.1.1 Northbound approach

It was only possible to evaluate whether there was a significant difference in mean saturation flow rates during different days of the week because very few queues extended beyond 4 vehicles during the morning peak period on the northbound approach. A one-way analysis of variance (ANOVA) was performed to evaluate the difference in mean saturation flow rates across the 5 weekdays. An *F* test for the equality of factor level means was constructed. Table 3 provides the results.

Controlling the significance level at $\alpha = 0.05$, $F_{0.95} = 2.37$. Since $F^* < F_{0.95}$, it can be concluded that there is no significant difference in saturation flow rates on the northbound approach between weekdays, Monday through Friday.

5.1.2 Southbound approach

With the data from the southbound approach, it was possible to examine whether there was a difference in mean saturation flow rates between morning and afternoon peak periods and between four weekdays, Tuesday through Friday. A two-way ANOVA was

TABLE 3 One-Way ANOVA: Effects of Day of the Week

Source	DF	SS	MS	*F**	P
Day	4	343506	85877	0.96	0.428
Error	671	59915735	89293		
Total	675	60259242			

to analyze these effects. Two-way ANOVA studies are much simpler when the sample sizes are equal. In this case, the sample sizes for the treatments range from a low of 24 for Friday morning to a high of 115 for Tuesday afternoon. For simplicity, the first 24 observations for each treatment were taken, and a two-way ANOVA was performed. Table 4 provides the results.

TABLE 4 Two-Way ANOVA: Effects of Time of Day and Day of the Week

Source	DF	SS	MS
Factor A – Time	1	555345	555345
Factor B – Day	3	789239	263080
Interaction (AB)	3	275964	91988
Error	184	34973236	190072
Total	191	36593784	

The analysis of the ANOVA results began with a test to determine whether or not the two factors interact. Controlling the significance level at $\alpha = 0.05$, $F_{0.95} = 2.60$, and $F^* = 0.48$. Since $F^* < F_{0.95}$ the interaction between time of day and day of the week is insignificant. As a result, the analysis continued by examining whether the main effects for factors A and B were important. Testing for time of day (factor A) effects, $F_{0.95} = 3.84$ and $F^* = 2.92$. Since $F^* < F_{0.95}$, there is no significant difference in mean saturation flow rates during the morning peak period versus the afternoon peak period. Testing for day of the week (factor B) effects, $F_{0.95} = 2.60$ and $F^* = 1.38$. Since $F^* < F_{0.95}$, there is no significant difference in mean saturation flow rates during different weekdays, Tuesday through Friday. The general linear approach, fitting both full and reduced models, was also performed utilizing all the data from the southbound approach. This approach confirmed the results from the two-way ANOVA.

5.2 Comparison of Saturation Headway Distributions

Another means of evaluating the effects of time of day and day of the week is by comparing headway distributions. The chi-squared test was used to assess statistically how closely one measured distribution was to another measured distribution. The southbound data were used to compare the distribution of headways during the morning peak versus the distribution of headways during the afternoon peak. The northbound data were used to compare the distribution of headways across days of the week.

5.2.1 Time of day

To perform the chi-square test, it is necessary to establish time headway intervals for the distributions. Nine intervals were established to compare time of day distributions. In addition, to compare measured distributions, the number of observations for both distributions needs to be equivalent. Since there were 173 observations for the morning peak period and 327 observations for the afternoon period, only the first 173 observations collected during the afternoon peak period were considered for the chi-square test. The resulting calculations are shown in Table 5. Holding the significance level at $\alpha = 0.05$, $\chi^2_{(0.95)} = 15.51$. Since $\chi^2_{(CALC)} < \chi^2_{(0.95)}$, the test shows that there is no significant difference in the distribution of headways during the morning peak period as compared to the afternoon peak period.

TABLE 5 Chi-Square Test Calculations Comparing Time of Day

Time Intervals (sec)	# of OBS (f_{AM})	# of OBS (f_{PM})	($f_{AM} - f_{PM}$)	($f_{AM} - f_{PM})^2$	($f_{AM} - f_{PM})^2 / f_{PM}$
0.8–1.29	9	4	5	25	6.25
1.30–1.49	18	14	4	16	1.14
1.50–1.69	31	35	–4	16	0.46
1.70–1.89	40	30	10	100	3.33
1.90–2.09	24	26	–2	4	0.15
2.10–2.29	22	29	–7	49	1.69
2.30–2.49	13	16	–3	9	0.56
2.50–2.69	7	7	0	0	0.00
2.70 +	9	12	–3	9	0.75
	173	173	0	$\chi^2_{(CALC)}$ =	14.34

5.2.2 Day of the week

With the northbound data, a total of 10 comparisons can be made between headway distributions across different days of the week. Table 6 provides the calculated chi-squared value for each of the respective comparisons and the $\chi^2_{(0.95)}$ value. In two comparisons, the chi-square test indicates the headway distributions are different. The headway distributions are statistically different on Tuesday as compared to Wednesday and Wednesday as compared to Friday. Note also that the four largest $\chi^2_{(CALC)}$ values are associated with Wednesday. This may indicate that something unusual in the traffic stream is occurring on Wednesdays.

6. CONCLUSIONS

The purpose of this research was to determine if the operational performance at signalized intersections varies depending upon the time of day and day of the week. If the operational performance varies, it could be reasoned that the difference is due to differing motivational factors in the driver population during the various times of the day and days of the week. Then, the driver population could be defined in terms of time of day and day of the week, and the operational differences could be accounted for in the capacity procedures for signalized intersections.

TABLE 6 Chi-Square Values Comparing Day of the Week

Comparison	$\chi^2_{(CALC)}$	$\chi^2_{(0.95)}$
MON vs. TUE	7.26	12.59
MON vs. WED	12.34	
MON vs. THUR	0.86	
MON vs. FRI	2.75	
TUES vs. WED	14.45	
TUES vs. THUR	2.93	
TUES vs. FRI	7.62	
WED vs. THUR	10.99	
WED vs. FRI	15.58	
THUR vs. FRI	3.07	

As it turns out, data from one intersection in State College, Pennsylvania, do not reveal any significant differences in operational performance of signalized intersections during different times of the day and days of the week. No differences were found in the mean saturation flow rates for the morning (7 am–9 am) peak period as compared to the afternoon (4 pm–6 pm) peak period. Likewise, no differences were found in the mean saturation flow rates for different weekdays, Monday through Friday. It would have been interesting to compare the saturation flow rates for weekdays as compared to weekends and peak periods versus non-peak periods, but the database did not allow for these comparisons.

Even though this research did not find any significant differences in the operational performance of signalized intersections during different times of the day and days of the week, it does reinforce the validity and accuracy of the current analysis procedure for signalized intersections in the HCM. In addition, no differences may have been found in the mean saturation flow rates, but some differences were found in the distribution of headways throughout the week. From a practitioners sense, this is not relevant, but from a researcher's perspective, it leads to the question of "why," which may stimulate further interest in this area.

Looking to the future, where should the research on the effects of driver population on the traffic operational performance of signalized intersections be heading? First, remaining on the idea of time of day and day of the week, it would be interesting to compare the saturation flow rates for weekdays as compared to weekends and peak periods versus non-peak periods. In addition, this research focused only on through movements. Future research should investigate headways for left-turn movements. Second, the current approach in the HCM to account for different driver populations on freeways and ramps has some obvious shortcomings. Future research should explore new approaches to define and account for differences in driver population at signalized intersections. For example, Zhou et al. (1999) recently developed driver population adjustment factors by area type. This was a creative new approach, and future efforts should continue to try innovative definitions for driver population. Third, on the issue of defining driver population by area type, are there additional area types for which adjustments may be developed? One example may be intersections located near special events. A second example could be intersections located near universities. The driver population is different when the universities are in session as compared to during breaks.

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